MINX Document 1
MISR - the Instrument, its Orbit and Data Products

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Contents

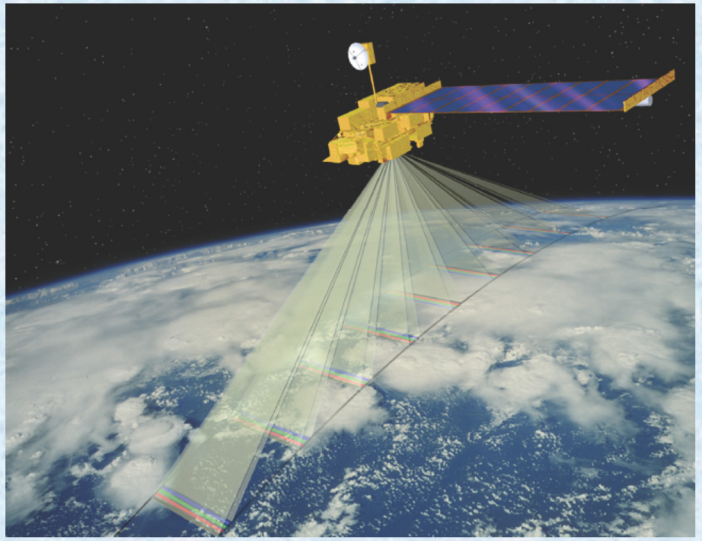
- Rationale for Multi-angle Measurements
- TERRA and its orbit
- The MISR instrument and data swath
- MISR coordinate system and file formats
- Introduction to MISR data products
  - Level 1 products
  - Level 2 products
  - Level 3 products

Why multi-angle?

1. Change in reflectance with angle distinguishes different types of aerosols, and surface structure

2. Oblique slant paths through the atmosphere enhance sensitivity to aerosols and thin cirrus

3. Stereo imaging provides geometric heights of clouds and aerosol plumes



4. Cloud motion, derived from time lapse (< 7 min) between cameras (forward to backward views), permits determination of winds aloft

5. Different observation angles enable sun glint avoidance or accentuation

6. Integration over angle is required to accurately estimate hemispherical reflectance (albedo)

Example areas of research

What is the abundance and distribution of different aerosol types, and how are these related to source locations and characteristics?

How does the surface respond to climate change or other disturbances? How does vegetation canopy structure affect photosynthetic and shortwave radiation fluxes?

How does 3-dimensional cloud structure affect our ability to relate cloud hydrological and radiative properties?

New ways of using MISR data are still likely to be discovered.

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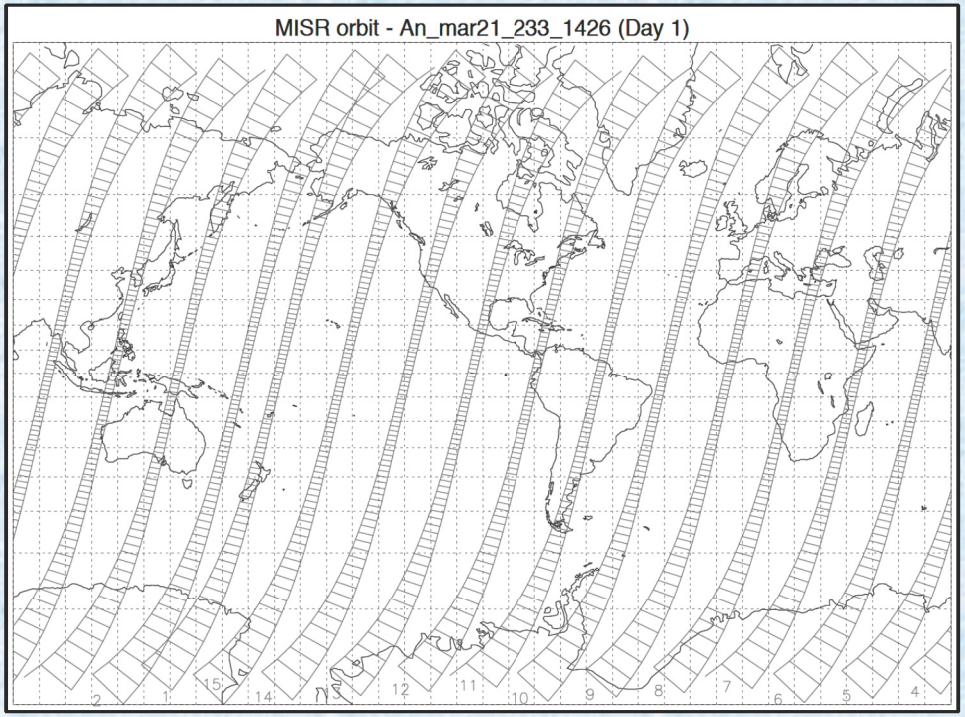
TERRA

- TERRA satellite or EOS AM-1
  - Launched December 18, 1999 from Vandenberg Air Force Base on Atlas II
  - 1st Earth Observing System mission

- TERRA carries 5 instruments:
  - ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)
  - CERES (Clouds and the Earth's Radiant Energy System)
  - MISR (Multi-angle Imaging Spectro-Radiometer)
  - MODIS (Moderate-resolution Imaging Spectro-radiometer)
  - MOPITT (Measurement of Pollution in the Troposphere)

TERRA Orbit

- 705 km, near polar orbit with inclination 98.3 degrees (retrograde)
- Sun-synchronous: orbital plane precesses with the same period as the earth's solar orbit period



Map showing consecutive orbits for one day courtesy of Brian Rheingans

- Occupies 233 orbital paths that repeat precisely every 16 days
- Descending orbit: travels from N to S on earth's day side (ascends on night side)
- Crosses equator at 10:30 AM local time on the day side for every orbit
- Orbital period is 99 min or almost 15 orbits/day
- Orbits are numbered consecutively from launch
- As of June 3, 2012, orbit number exceeded 66,200
- Enough fuel to fly till 2018

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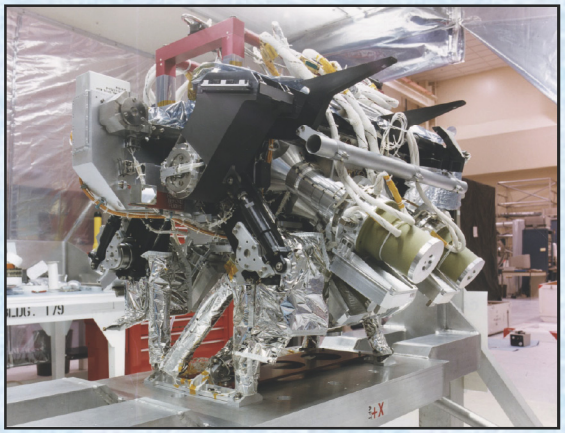
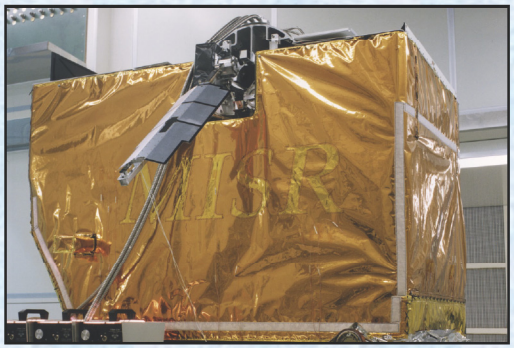
MISR Instrument

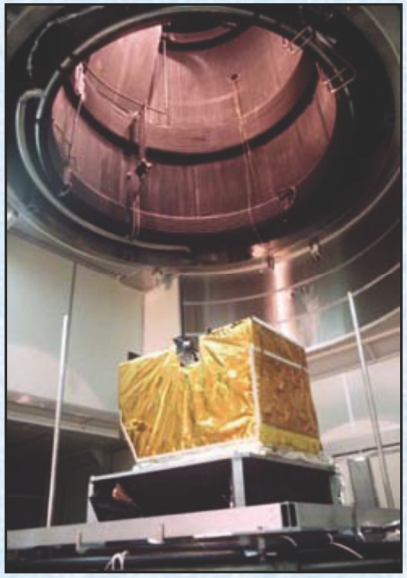
Family portrait



The “V-9” optical bench



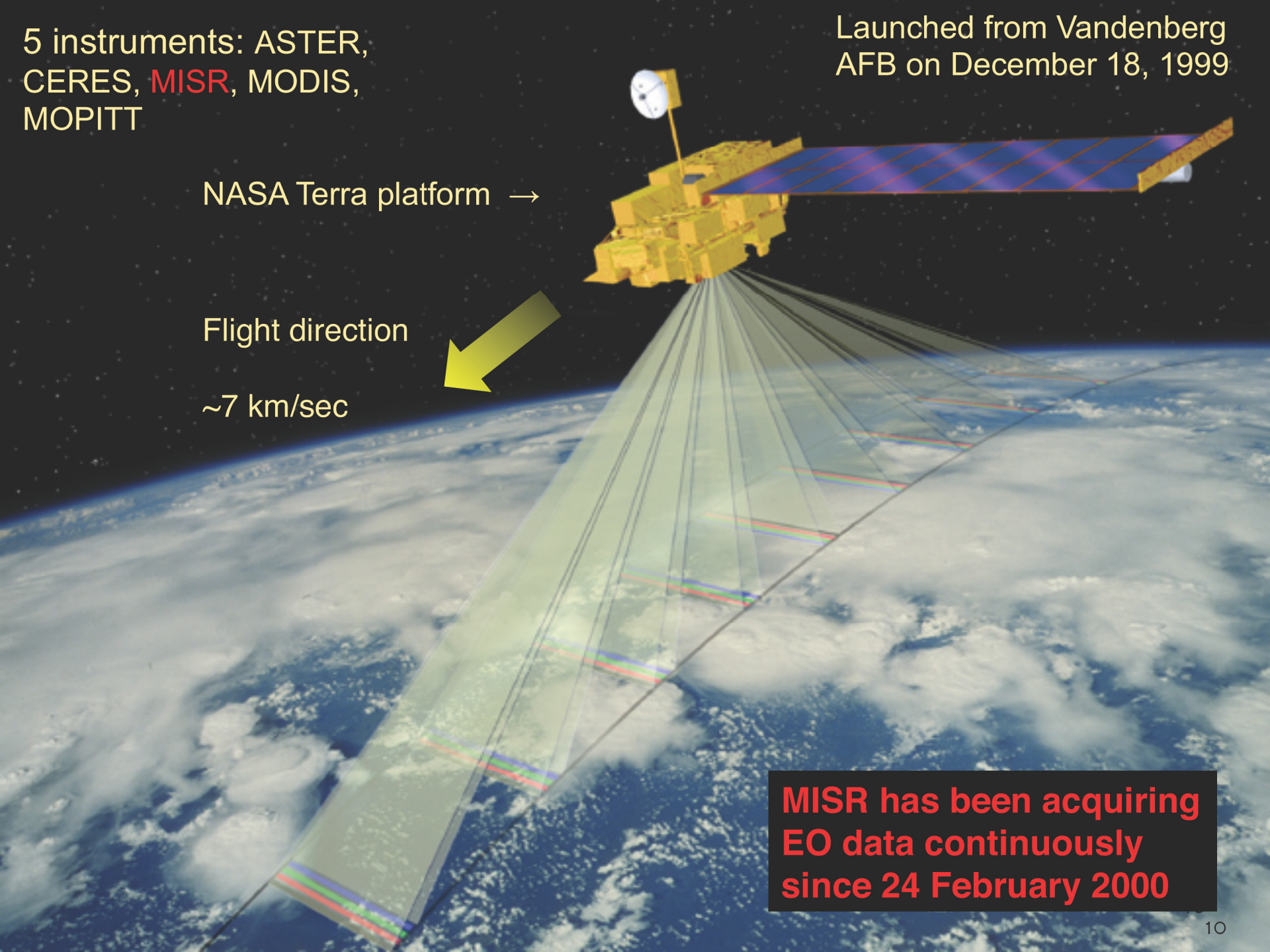
Undergoing test

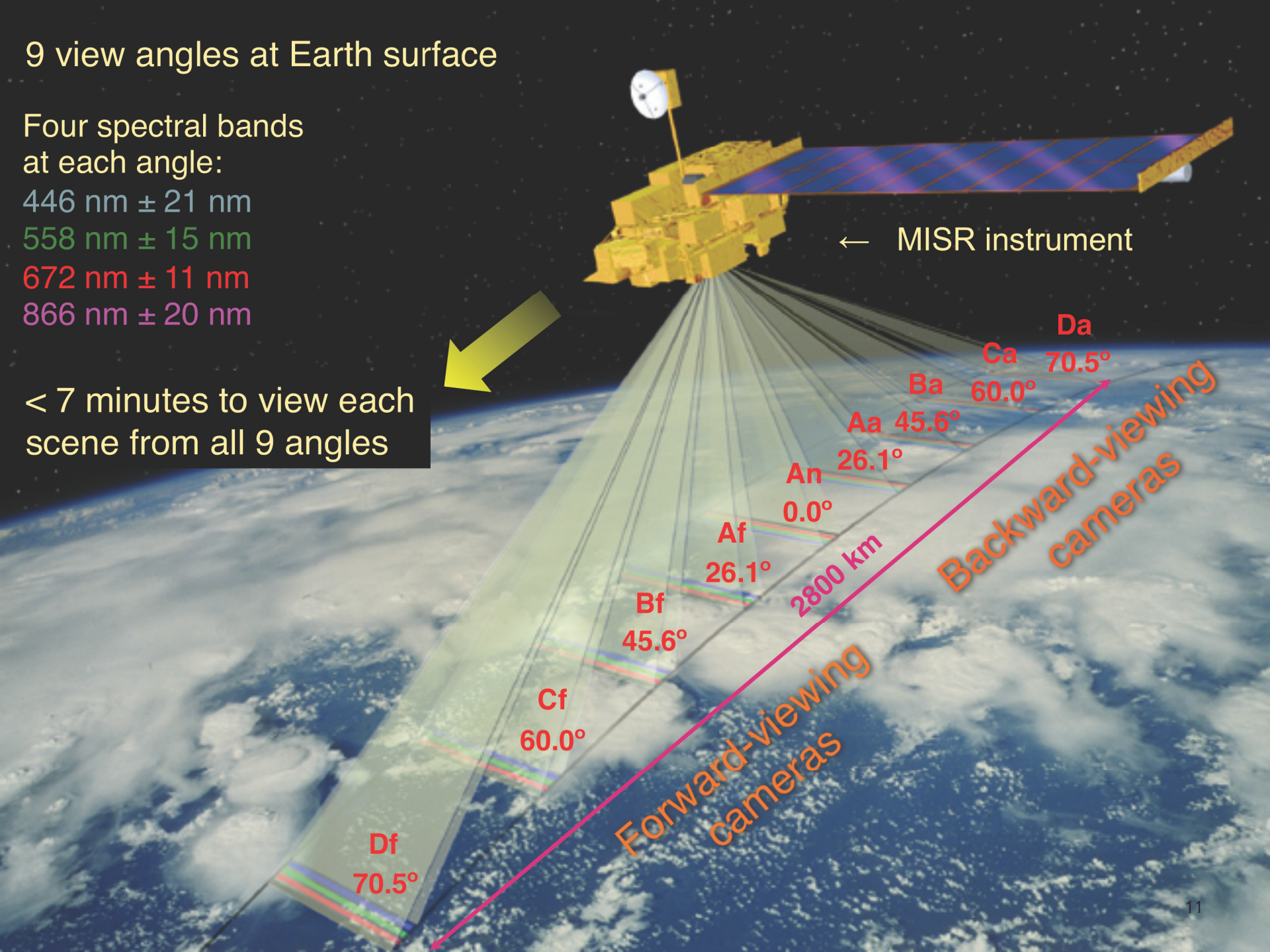


JPL’s Space Simulator Facility

MISR on Terra spacecraft

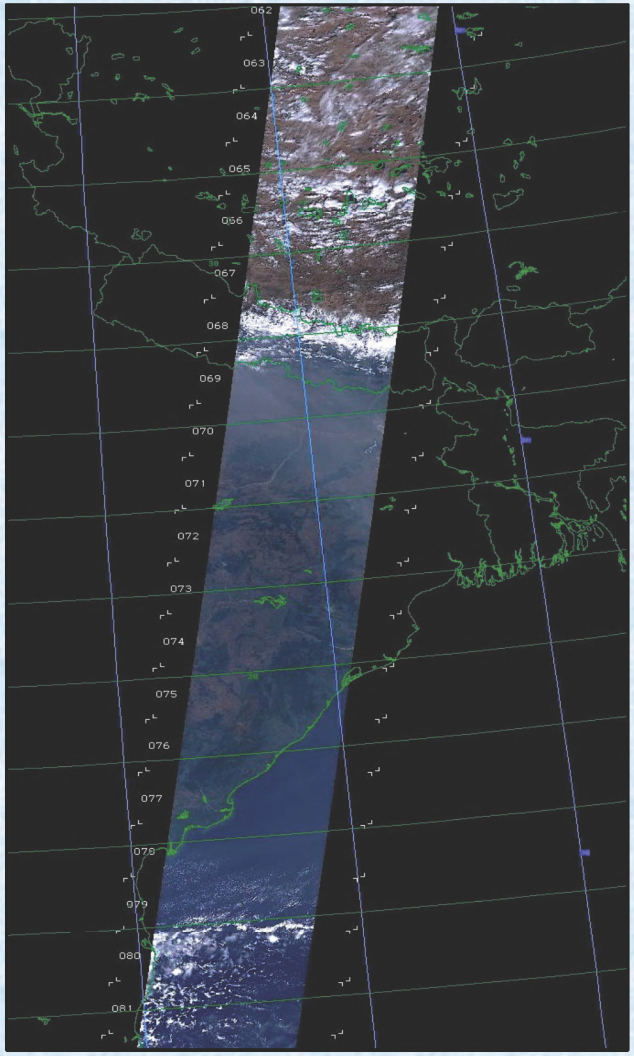
Terra launch 18 December, 1999


5 instruments: ASTER, CERES, MISR, MODIS, MOPITT
Launched from Vandenberg AFB on December 18, 1999
NASA Terra platform →
Flight direction
~7 km/sec
MISR has been acquiring EO data continuously since 24 February 2000


9 view angles at Earth surface
Four spectral bands
at each angle:
446 nm ± 21 nm
558 nm ± 15 nm
672 nm ± 11 nm
866 nm ± 20 nm
< 7 minutes to view each
scene from all 9 angles
← MISR instrument
Da
70.5°
Ca
60.0°
Ba
45.6°
Aa
26.1°
An
0.0°
Af
26.1°
Bf
45.6°
Cf
60.0°
Df
70.5°
2800 km
Backward-viewing
cameras
Forward-viewing
cameras

MISR Data Swath - 1

- Push-broom: line of 1504 fixed detectors per channel rather than one scanning detector
- Each detector views a strip on the ground 275 m wide across-track producing common camera overlap width of ~ 380 km
- Sampling rate in along-track direction about 25/sec yields a 275 m ground sample interval
- Global Mode operation (normal):
  - 275 x 275 m pixels in 12 channels (high res)
    - Red band in all 9 cameras
    - All 4 bands in nadir (An) camera
  - 1100 x 1100 m in other 24 channels (low res)
  - Accomplished by on-board averaging
- Local Mode operation (by request):
  - 275 x 275 m pixels in all 36 channels
  - Data rate ~20 Mbits/sec prohibitive for routine operation - reserved for special requests

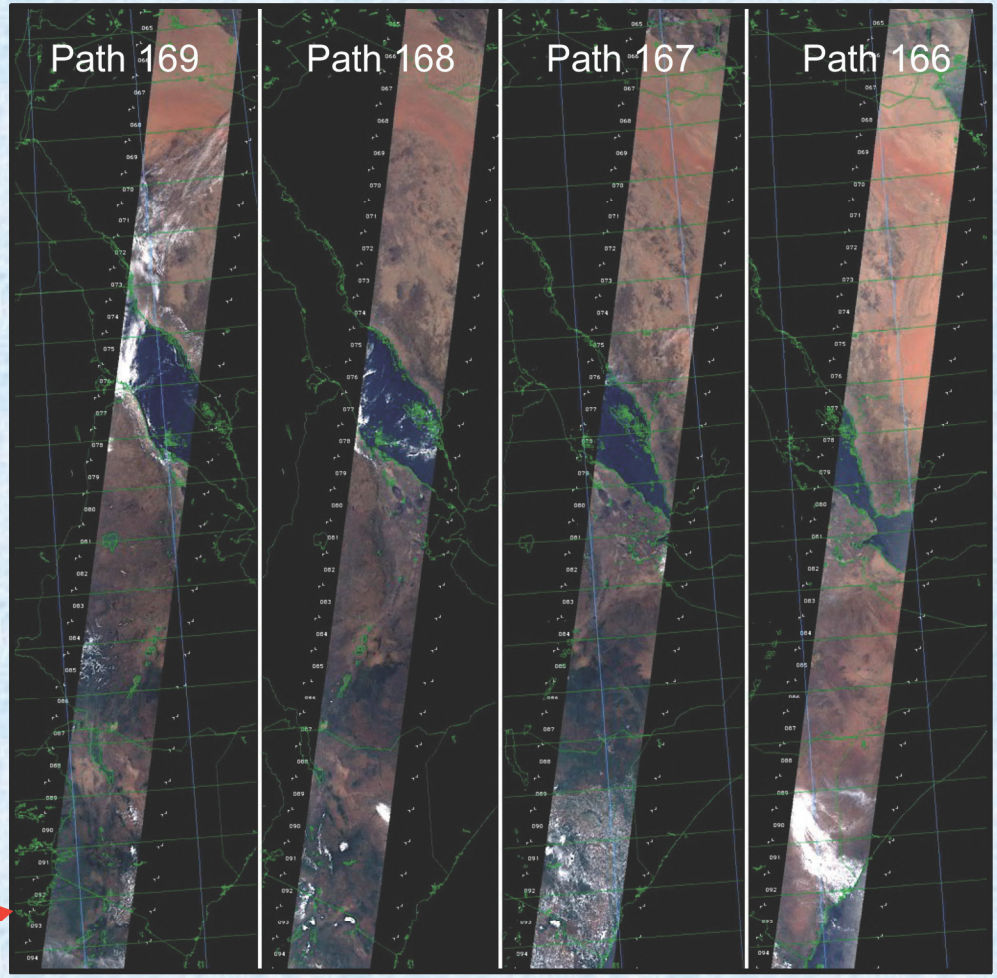


2.2 km resolution browse image over Nepal

MISR Data Swath - 2

- Paths overlap by more than a factor of 2 at equator
- Ground-track repeat cycle is 16 days, but global coverage is obtained in < 9 days at equator
- At high latitudes, coverage is obtained every 2 days due to orbit convergence
- No coverage within 8 degrees of the poles

Note - these orbits are on consecutively numbered paths, but the orbits are not consecutively numbered - they are from different dates!



2.2 km resolution orbit images over Arabian peninsula and East Africa from 4 consecutive paths illustrating path overlap

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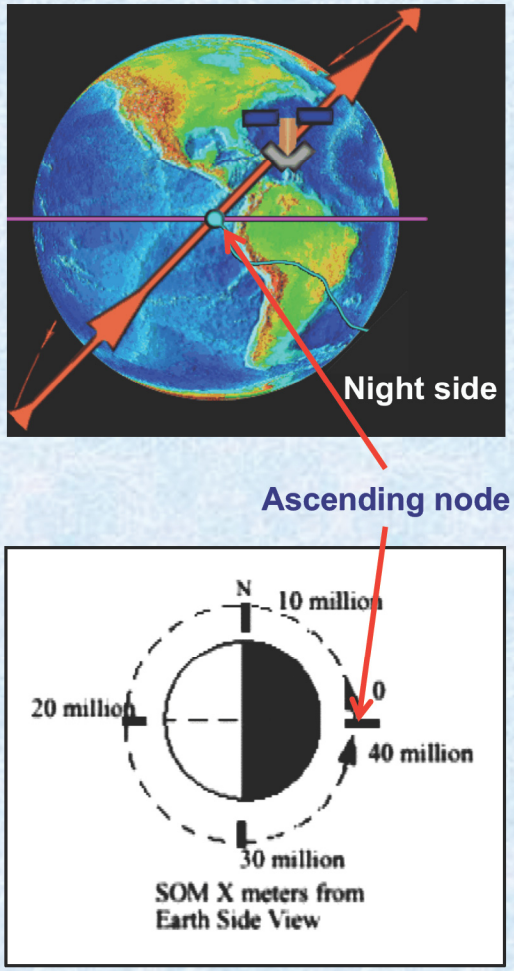
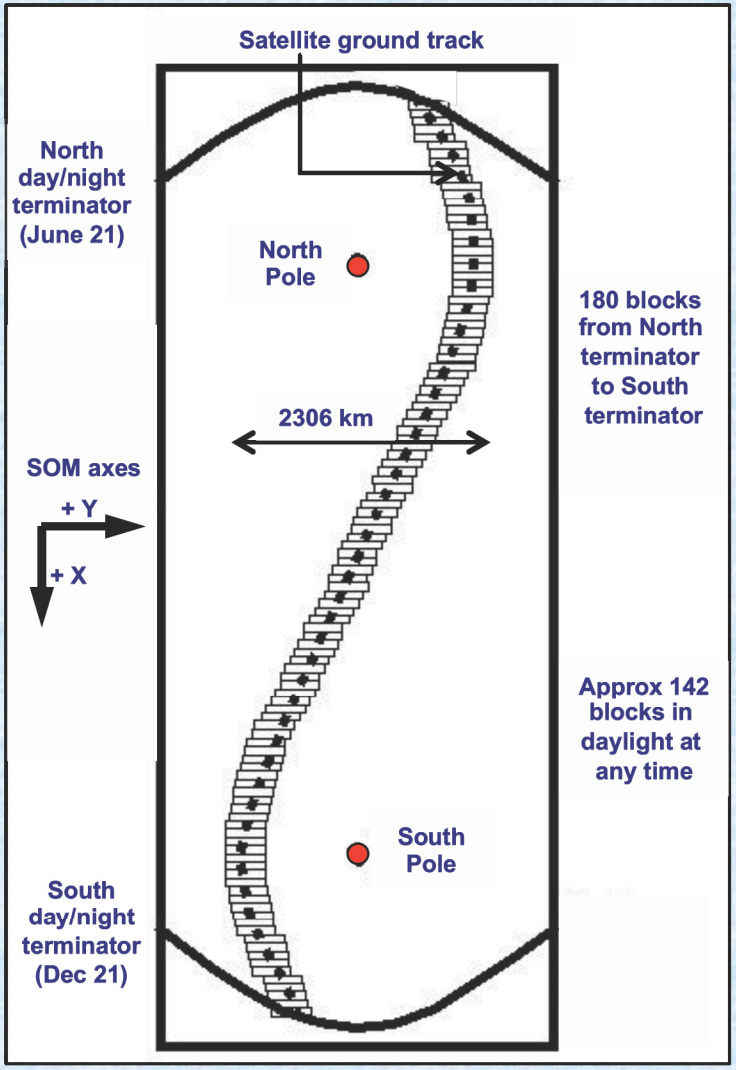
Mapping MISR Data: Paths and SOM Projection

- Terra follows a pattern of orbits which repeats precisely after occupying 233 unique paths
- The origin of each path is where the satellite crosses the ascending node – the equator on the night side
- Satellite ground track defines a curved line on earth's surface that becomes the center of a modified oblique Mercator projection called Space Oblique Mercator (SOM)
- SOM minimizes re-sampling distortions
- A separate SOM projection is defined for each of MISR's 233 paths



Mapping MISR Data: SOM and Blocks

- Dayside path extends from terminator in north on June 21 to terminator in south on Dec 21
- Each dayside path subdivided into 180 Blocks in North/South direction
- Only ~142 blocks have data for any orbit - extra blocks allow for seasonal variation in solar illumination
- Each block may be offset relative to the one above it to maintain ground track near center of block
- Each block is 2048 pixels wide and 512 pixels high → 563.2 km x 140.8 km
- Any particular block number lies at the same latitude for all MISR paths

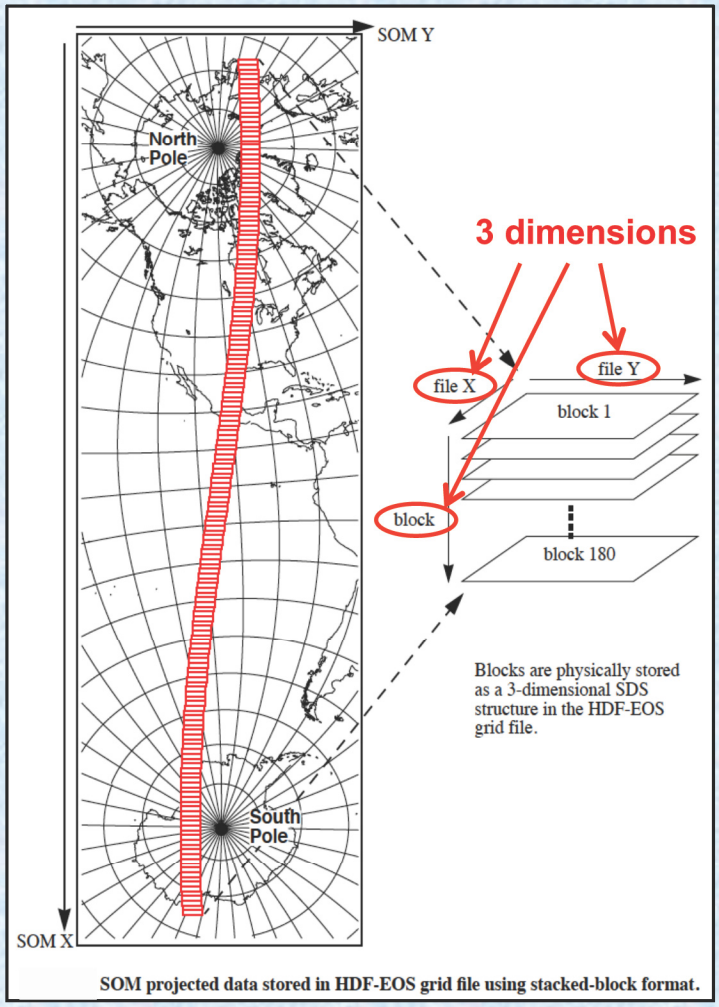


MISR File Format : Stacked Block

- MISR data are stored as a "stack" of blocks using the HDF grid data type (Hierarchical Data Format)
- Stacked blocks are not EOS standard, so most HDF viewers can't read MISR data
- Every MISR product contains 180-block grids to make block indexing consistent
- Gridded data are indexed differently according to pixel size for the data type

Pixel size:	275 m	1100 m	17600 m	etc.
Block	1-180	1-180	1-180	
Sample	1-2048	1-512	1-32	
Line	1-512	1-128	1-8	

- MISR data can be ordered subsetted to include only a selected block range to reduce data volume



SOM projected data stored in HDF-EOS grid file using stacked-block format.

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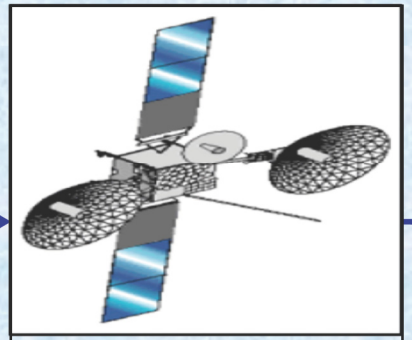
MISR Data Flow

MISR instrument acquires data and sends it to data recorder on TERRA for relay to TDRSS



TDRSS geostationary satellite relays data to ground station

White Sands, New Mexico ground station relays data to EDOS

EOS Data and Operations System (EDOS)
NASA Goddard Space Flight Center, Maryland

Distributed Active Archive Center (DAAC)
NASA Langley Research Center, Virginia

DAAC installs Product Generation Executables (PGEs), receives daily raw orbit data from EDOS and runs the PGEs against orbit data; also archives data products & distributes data and software tools to users

Delivery of processed products

Worldwide Users

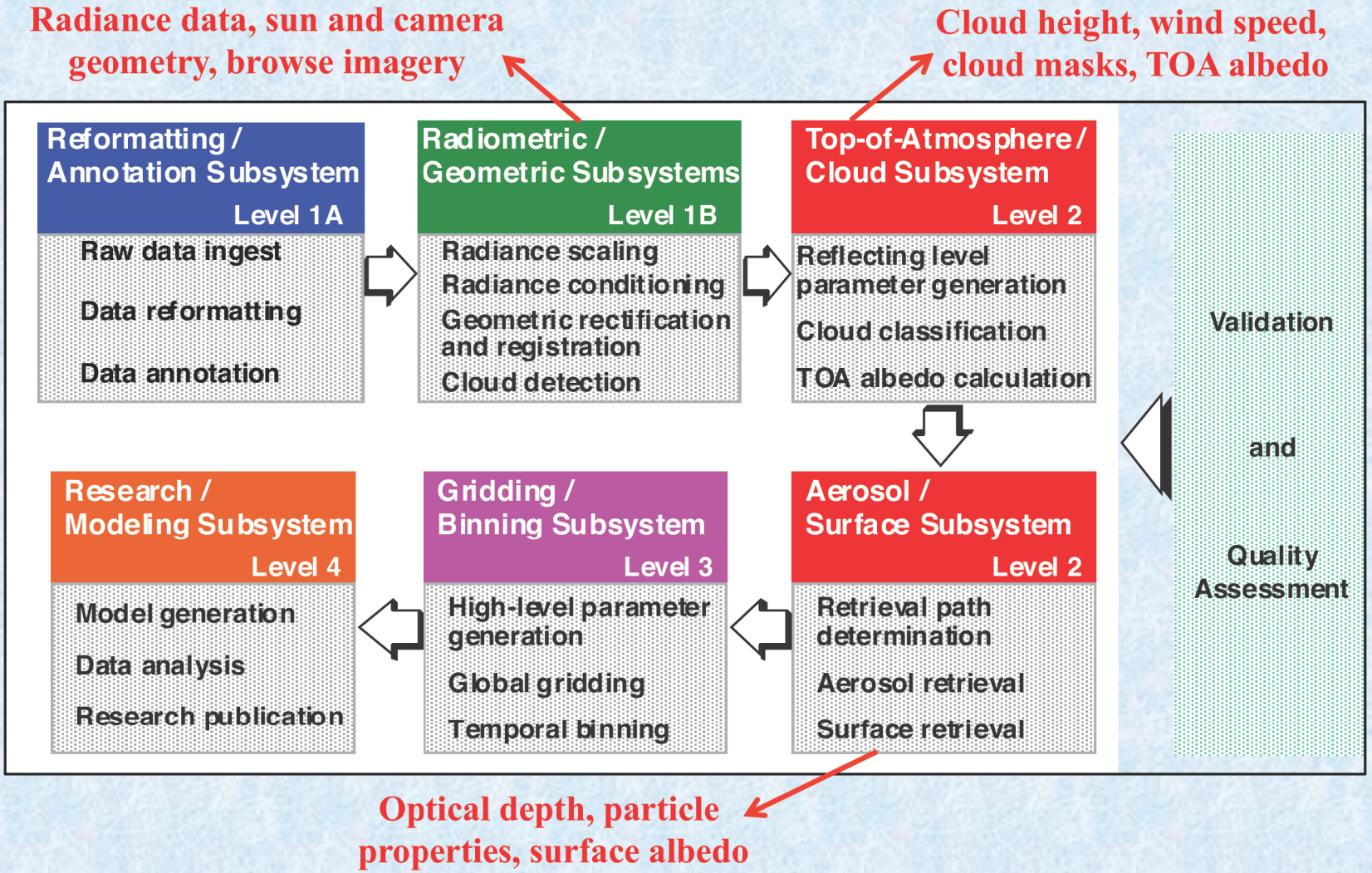
Delivery of processing software

MISR Science Computing Facility (SCF)
NASA Jet Propulsion Lab, Pasadena, CA

MISR science team develops data processing algorithms; MISR data team writes Product Generation software and periodically delivers code updates to the DAAC

Delivery of processed products

MISR Data Product Generation



Standard Product Naming Convention

MISR_AM1_GRP_TERRAIN_GM_P028_O002510_AN_F03_0024_b058-062.hdf

MISR	**- instrument name - constant for all MISR products**
AM1	**- satellite name - constant for all MISR products**
GRP_TERRAIN	**- MISR product type**
GM	**- acquisition mode (if pertinent: GM = Global Mode, LM = Local Mode)**
P028	**- TERRA Path number (1 - 233)**
O002510	**- TERRA Orbit number (995 – 66,000+)**
AN	**- camera name (if pertinent: DF, CF, BF, AF, AN, AA, BA, CA, DA)**
F03	**- format version number (format of product file)**
0024	**- product version number (algorithm that created product)**
b058-062	**- block range (if file was subsetted during the data ordering process)**
hdf	**- hierarchical data format (standard HDF-EOS file structure)**

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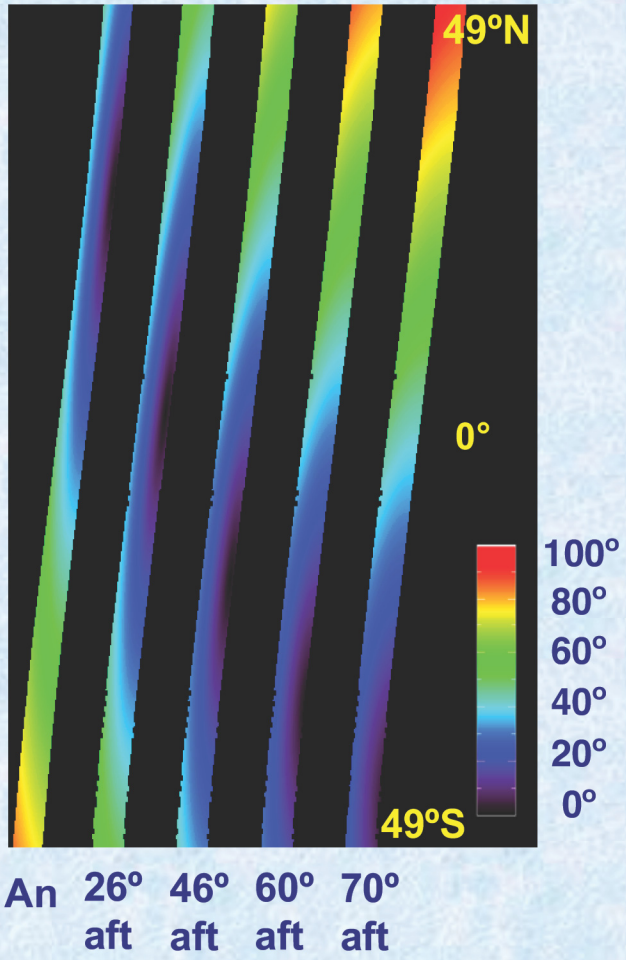
Level 1 Standard Data Products (L1B2)

- Level 1B2 geometric parameters
  - Camera and sun angles (zenith, azimuth, scatter, glitter)
  - Resolution: 17.6 km; File size: ~ 11 Mbytes
  - MISR_AM1_GP_GMP_P028_O002510_F03_0013.hdf
- Level 1B2 geo-rectified radiance product (images)
  - One product file per camera; 4 bands in each file
  - Resolution: 275 m and 1100 m
  - Ellipsoid projected: File size: ~ 600 Mbytes for An cam, ~ 200 Mbytes for off-nadir cameras
    MISR_AM1_GRP_ELLIPSOID_GM_P028_O002510_AN_F03_0024.hdf
  - Terrain projected: File size: ~ 150-450 Mbytes for An camera, ~ 50-150 Mbytes for off-nadir cameras
  - MISR_AM1_GRP_TERRAIN_GM_P028_O002510_AN_F03_0024.hdf
- Level 1B2 browse product
  - RGB images of GRP_ELLIPSOID radiances in JPEG
  - Resolution: 2.2 and 4.4 km; File size: ~ 0.5 Mbytes
  - One file per camera
  - Blocks are assembled into continuous swath for entire orbit
  - MISR_AM1_GRP_ELLIPSOID_BROWSE_GM_P028_O002510_AN_F03_0024.jpg

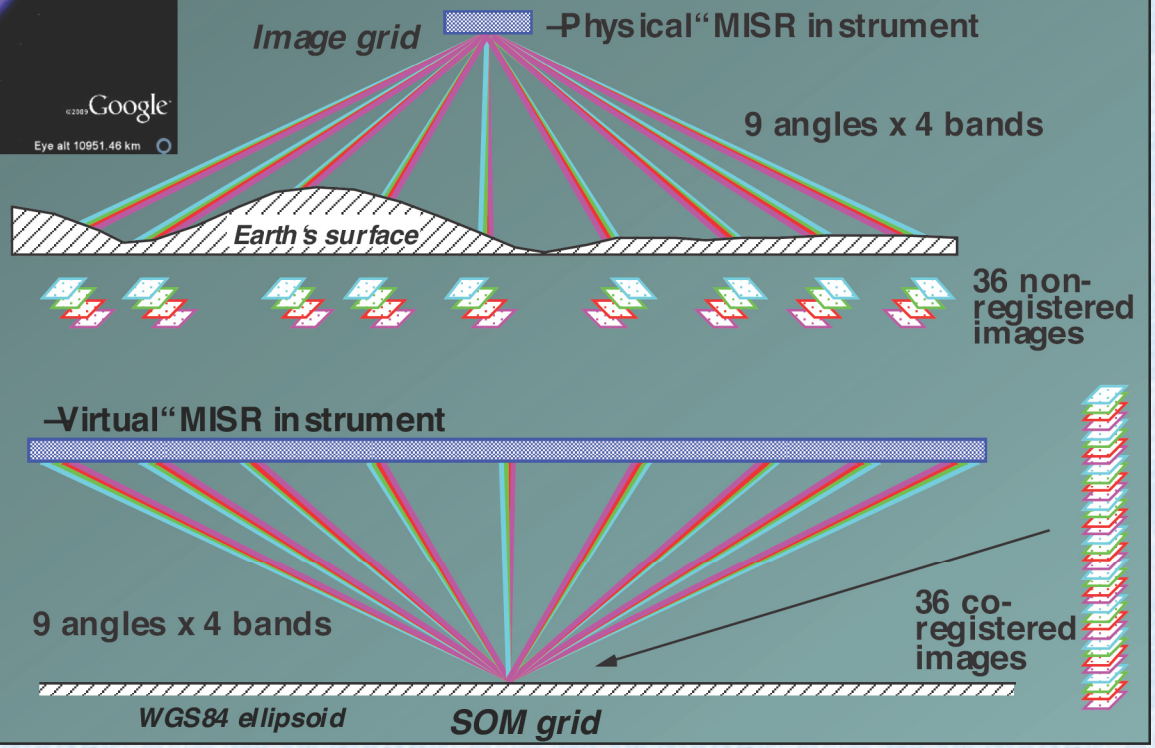
Example of glitter angle, July 3



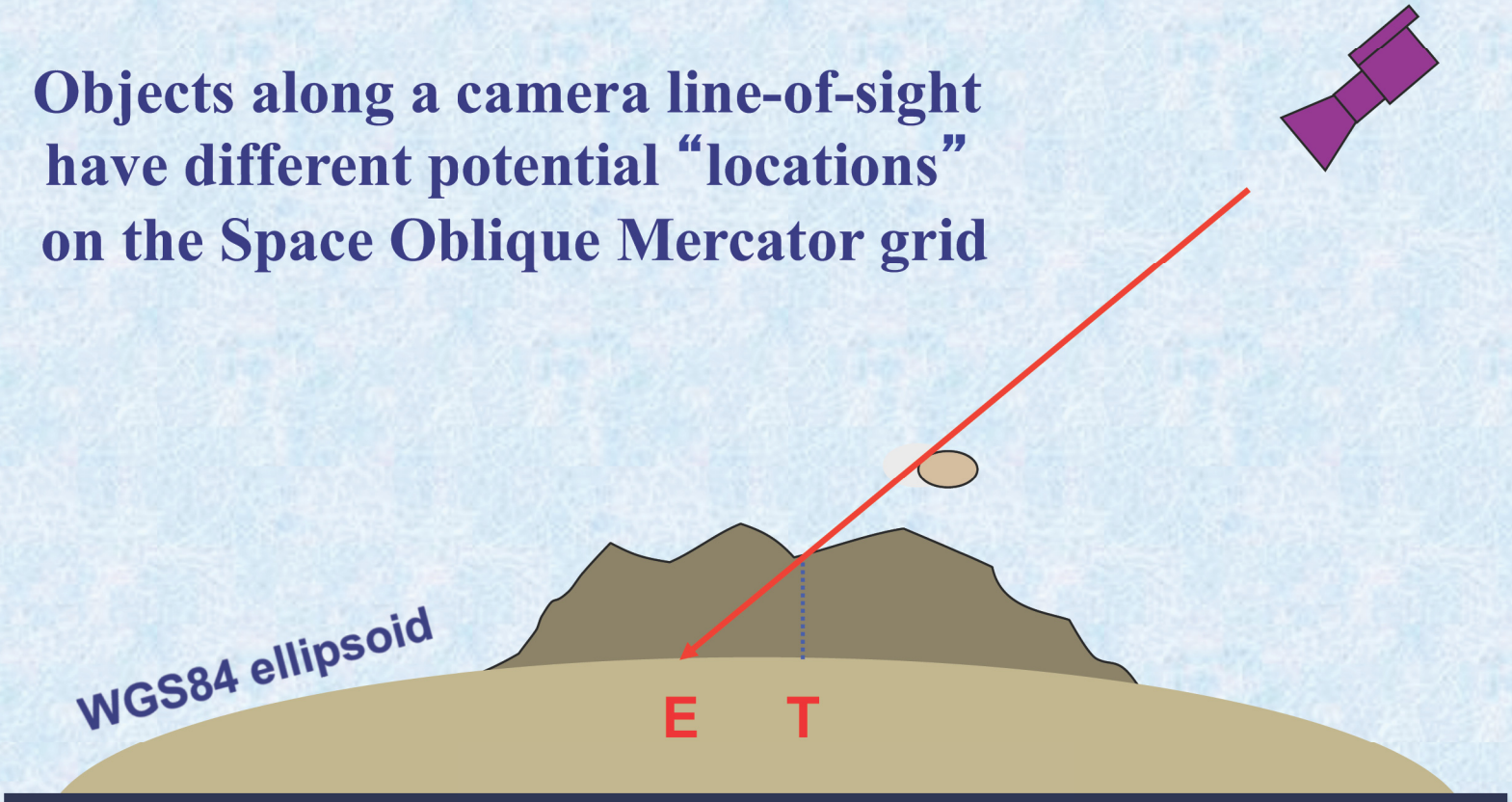
MISR geo-location and angle-to-angle co-registration on Space Oblique Mercator (SOM) projection

Space Oblique Mercator projection minimizes re-sampling distortions

233 unique paths in 16-day repeat-cycle of Terra orbit



Objects along a camera line-of-sight have different potential "locations" on the Space Oblique Mercator grid

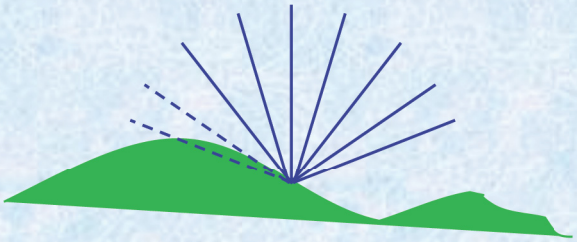


E = ellipsoid-projected location
T = terrain-projected location

Camera-to-camera Co-registration Requires Establishing a Reference Altitude

"Ellipsoid projection" is to the WGS84 ellipsoid

- performed during Level 1 processing
- used as input to stereoscopic processing



"Terrain projection" is to a digital elevation model

- performed during Level 1 processing
- used as input to aerosol/surface processing and MINX
- some views may be obscured

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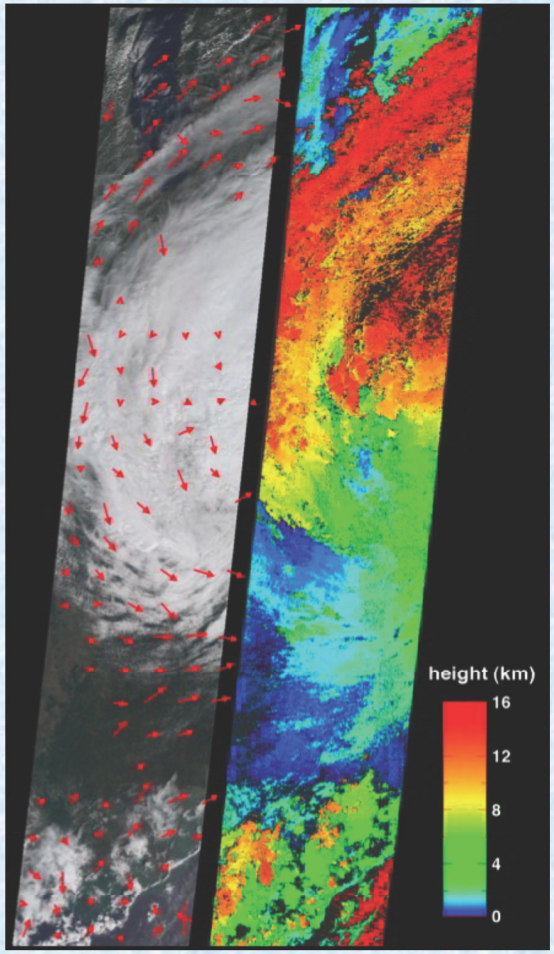
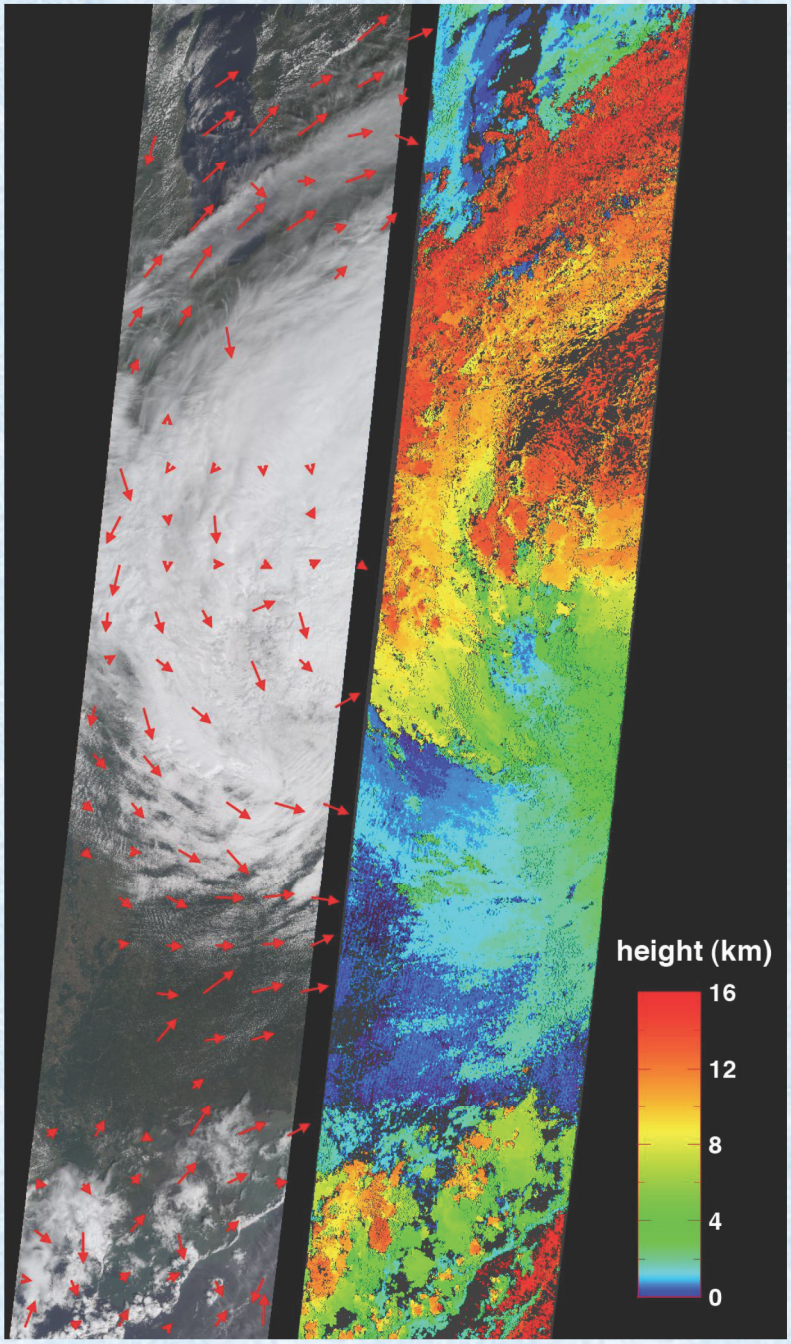
Level 2 TC Standard Data Products (L2TC)

- **Level 2TC stereo**
  - Contains cloud heights, wind speeds, stereo cloud mask ...
  - Resolution: 1.1 km cloud heights and cloud mask; 70.4 km winds
  - File size: ~ 80 MBytes
  - A new algorithm is now running at the DAAC – provides *significant* improvement in coverage, accuracy and resolution – MINX can't read new product yet
  - MISR_AM1_TC_STEREO_P028_O002510_F08_0017.hdf
    MISR_AM1_TC_STEREO_FIRSTLOOK_P028_O002510_F08_0017.hdf
- **Level 2TC classifiers**
  - Contains, angular signature cloud mask, SVM scene classifier ...
  - Resolution: 1.1 km SVM classifier and cloud mask
  - File size: ~ 37 MBytes
  - MISR_AM1_TC_CLASSIFIERS_P028_O002510_F06_0011.hdf
    MISR_AM1_TC_CLASSIFIERS_FIRSTLOOK_P028_O002510_F06_0011.hdf
- **Level 2TC top-of-atmosphere (TOA) albedo**
  - Contains local, restrictive and expansive albedo, BRF ...
  - Resolution: 35.2 km restrictive and expansive albedo; 2.2 km local albedo; and 1.1 km BRF
  - File size: ~ 480 MBytes
  - MISR_AM1_TC_ALBEDO_P028_O002510_F05_0011.hdf
    MISR_AM1_TC_ALBEDO_FIRSTLOOK_P028_O002510_F05_0011.hdf



Stereo heights and winds for Hurricane Katrina 8/30/05



L2 TOA/Cloud Stereo Product

Cloud heights and cloud-tracked winds

HEIGHT ATTRIBUTES

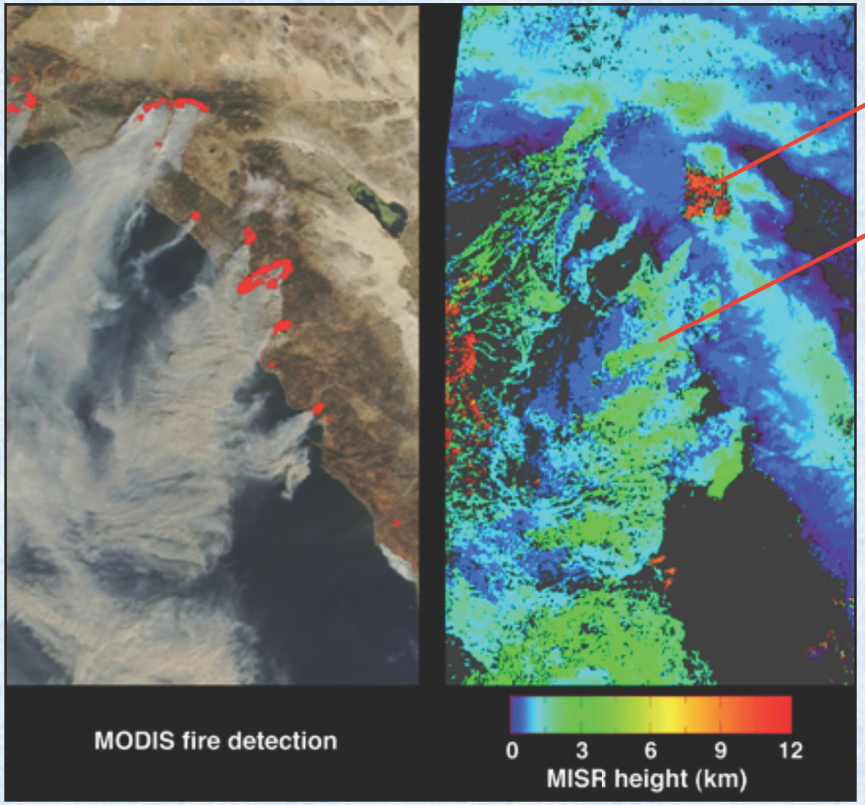
- 1.1-km resolution
- Purely geometric retrievals of height
- Independent of temperature profiles and cloud emissivity
- Independent of radiometric calibration
- Accuracy 500 -1000 m

WIND ATTRIBUTES

- 70.4-km resolution
- Uses stereo triplets
- Accuracy 1-3 m/s with 300 m height resolution

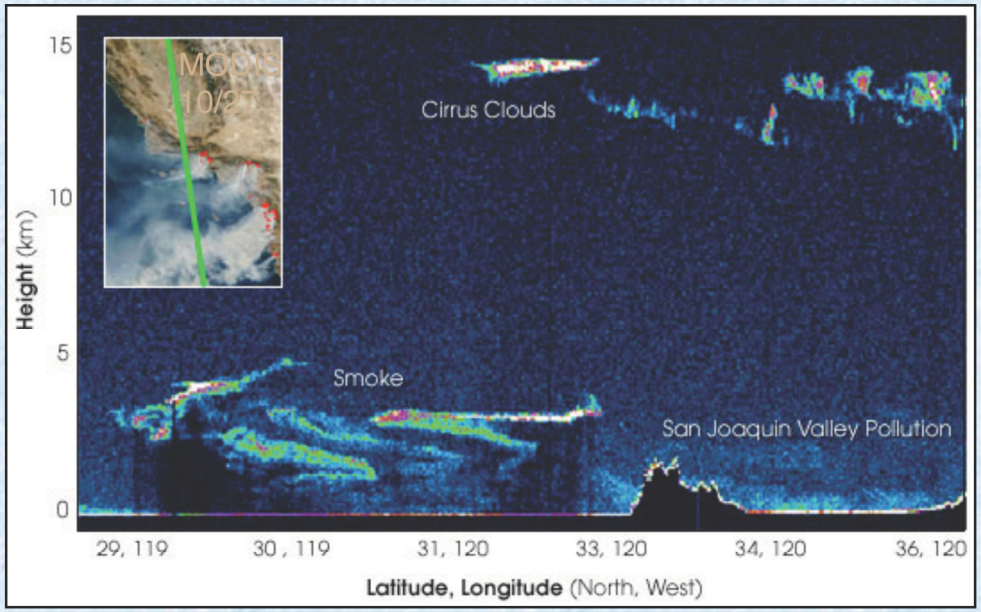
Hurricane Katrina
30 August, 2005

Measuring Wildfire Smoke Plume Injection and Transport Heights



MODIS/MISR data from Terra
26 October, 2003

GLAS vertical profiles
28 October, 2003



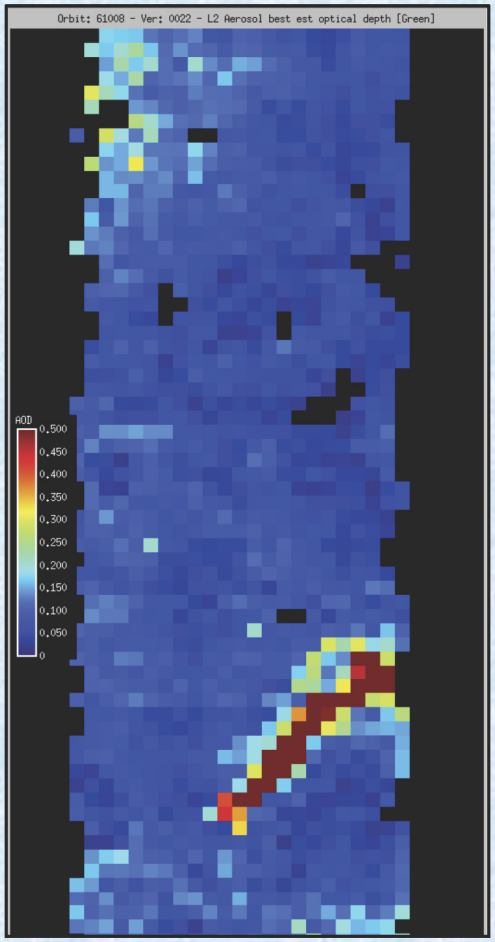
Geoscience Laser Altimeter System (GLAS) hosted on the ICESat platform, launched on 13 January, 2003

Level 2 AS Standard Data Products (L2AS)

- **Level 2AS aerosol**
  - Contains spectral optical depth, angstrom exp, ...
  - Resolution: 17.6 km, 1.1 km and 70.4 km
  - File size: ~ 25 Mbytes
  - MISR_AM1_AS_AEROSOL_P028_O002510_F12_0022.hdf
    MISR_AM1_AS_AEROSOL_FIRSTLOOK_P028_O002510_F12_0022.hdf
- **Level 2AS land surface**
  - Contains surface albedo, NDVI, RPV coefficients …
  - Resolution: 1.1 km for most parameters
  - File size: ~ 5 - 300 MBytes
  - MISR_AM1_AS_LAND_P028_O002510_F07_0022.hdf
    MISR_AM1_AS_LAND_FIRSTLOOK_P028_O002510_F07_0022.hdf

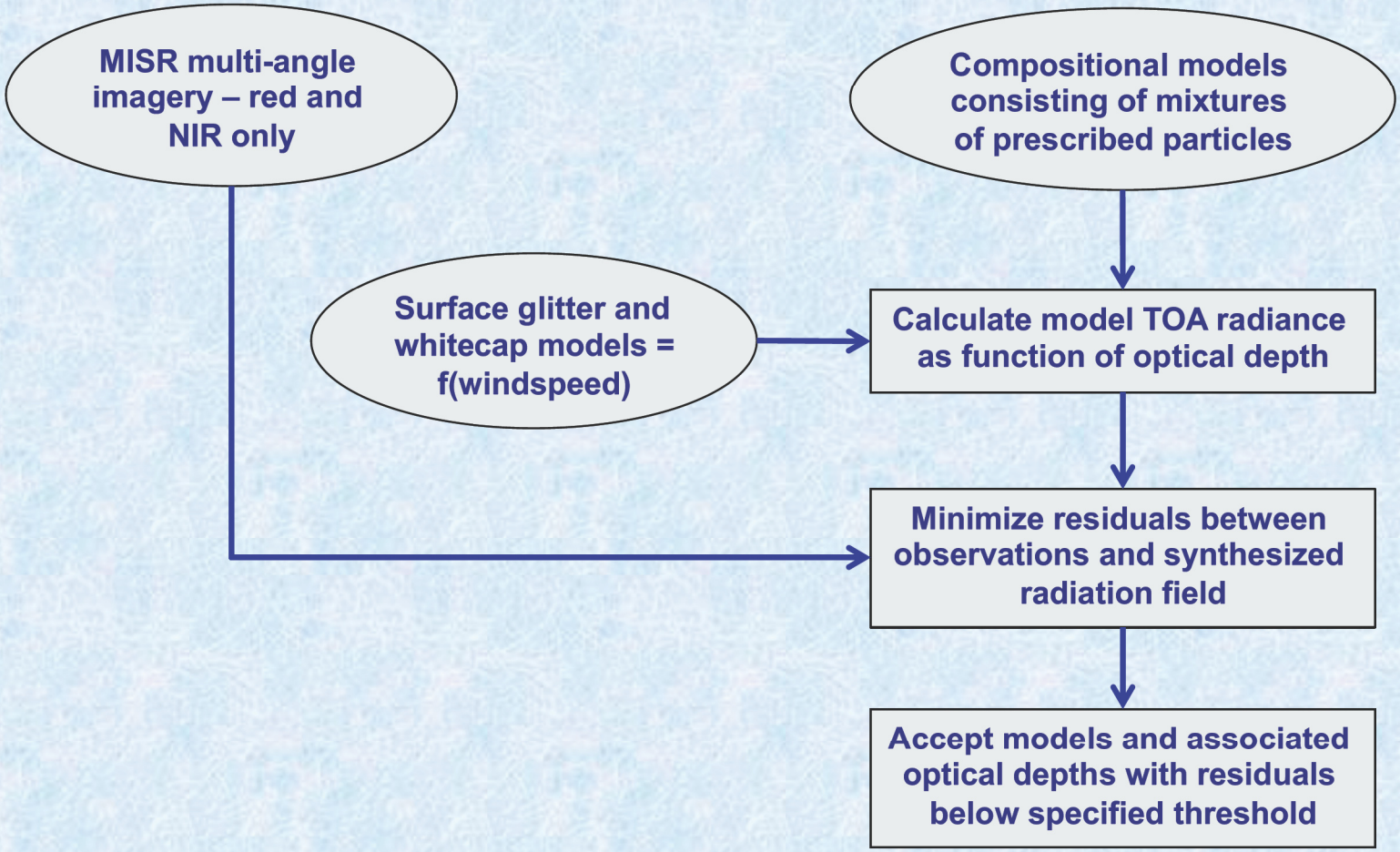
Also a Level 2 product:

- **Level 2 radiometric camera-by-camera cloud mask**
  - 9 camera files each containing cloud masks
  - Resolution: 1.1 km
  - File size: ~ 50 Mbytes per camera
  - MISR_AM1_GRP_RCCM_GM_P067_O023963_AN_F04_0025.hdf
    MISR_AM1_GRP_RCCM_LM_P067_O023963_AN_F04_0025.hdf

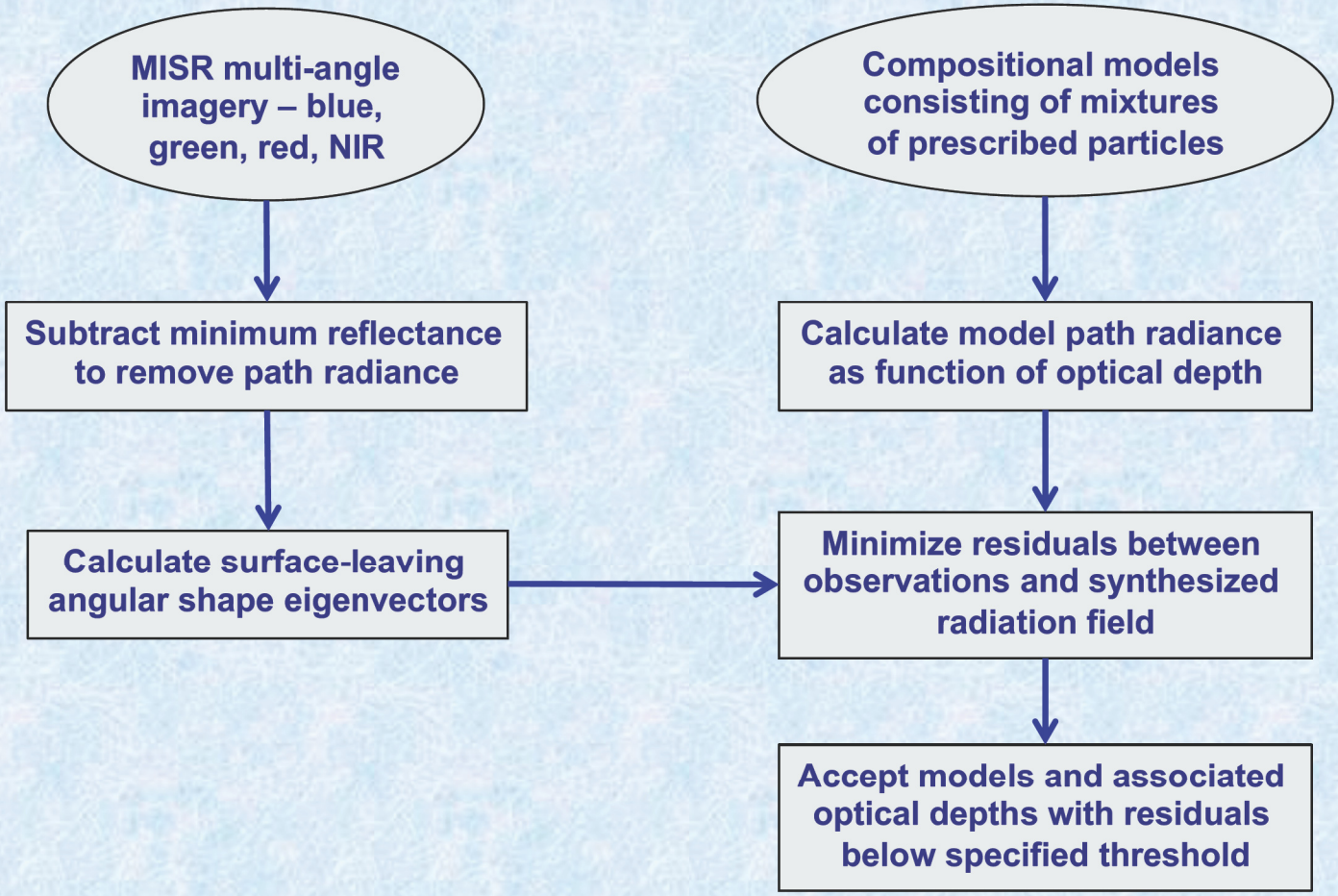


Orbit 61008
Best estimate aerosol optical depth with smoke plume near bottom right

Level 2 Aerosol Product Algorithm Overview – 1 Dark Water



Level 2 Aerosol Product Algorithm Overview – 2 Heterogeneous Land



MISR Level 2 Aerosol Product Key Fields

RegBestEstimateSpectralOptDepth – 4 values, the mean of all successful models in the climatology
RegBestEstimateSpectralOptDepthUnc – 4 values, standard deviation of all successful models
RegBestEstimateAngstromExponent – slope of linear least-squares fit to log AOTs vs. log of four wavelengths
RegBestEstimateSpectralSSA – aggregated among successful models by binning rules
RegBestEstimateSpectralOptDepthFraction -- AOT fraction grouped by (1) rad < 0.35; (2) 0.35 < rad < 0.7; (3) rad > 0.7; (4) spherical; (5) non-spherical
RegBestEstimateNumberFraction – five fractional values, based on relative particle number concentration
RegBestEstimateVolumeFraction – five fractional values, volume-weighted
RegBestEstimateQA – 0=1 successful mixture; 1= (>1) successful mixtures; 2=not used; 3=no successful mixtures
RegLowestResidSpectralOptDepth, etc. – value for mixture having lowest ChiSqAbs or ChiSqHet

AlgTypeFlag – gives the algorithm type used for the region: 1=dark water; 3=het. land, 253=fill
RegClassInd – 0=clear; 1=solar oblique; 2=topo. complex; 3=cloudy; 4=no data; 253=fill
AerRetrSuccFlag – 1=no successful mixtures; 3=algorithm failure; 5=insufficient data; 7=successful retrieval
NumSuccAerMixture – number of successful mixtures
NumCamUsed – number of cameras with good data and not in glint (max=9)
NumAcceptSubr – number of 1.1 km sub-regions within region passing all criteria for use (max=256)
RegEqRefl – observed regional equivalent reflectances used in retrieval (max=36)
SolZenAng, ScatterAng, GlitterAng, etc. – region-specific geometry
AerRetrSuccFlagPerMixture – 1=mixture successful; 251, 252, 253=mixture not successful
OptDepthPerMixture – lowest resid. AOT for each mixture, successful or not. (V15 max=24; V16 max=74)
ChisqAbs, Geom, Spec, Maxdev, Het – per mixture ChiSq values, whether the mixture was successful or not

RetrAppMask (SubregParamsAer) – 0=clear; 1=missing data; 2=poor quality; 7=cloudy, etc.

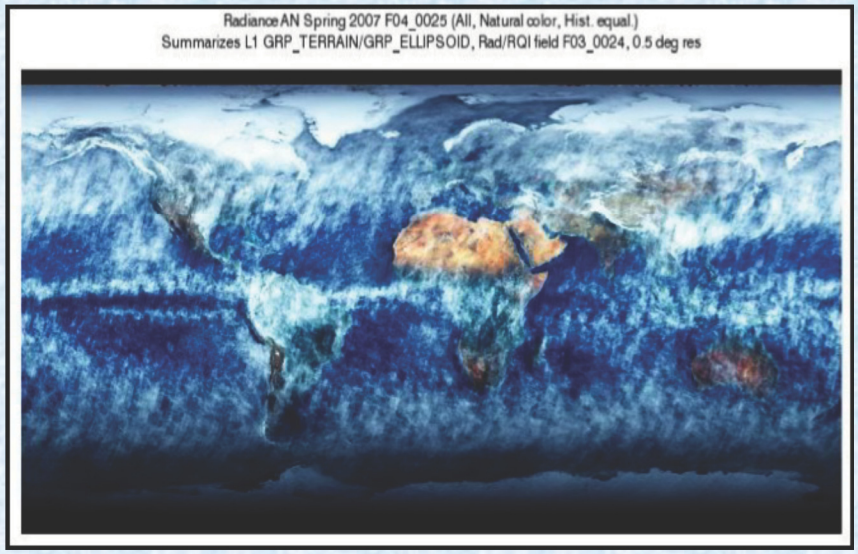
Reference: MISR Data Product Specification document, Section 8: Level 2 Aerosol/Surface Product

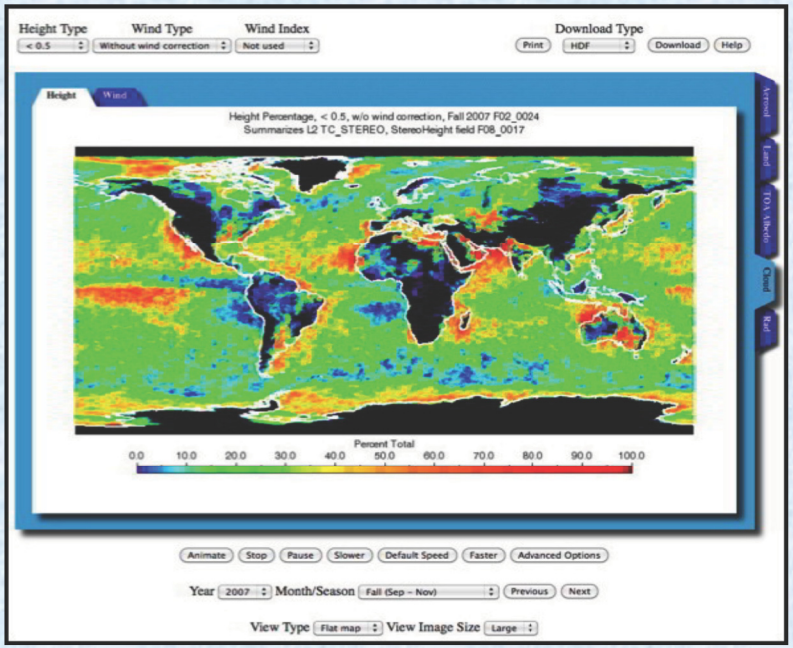
Contents

- Rationale for Multi-angle Measurements
- TERRA and its orbit
- The MISR instrument and data swath
- MISR coordinate system and file formats
- Introduction to MISR data products
  - Level 1 products
  - Level 2 products
  - Level 3 products

Level 3 Global Data Products (L3) - DAAC

- Contain globally gridded summaries of Level 1 and 2 data products
  - Radiances for 9 cameras
  - Aerosol optical depth
  - Surface albedo, NDVI, FPAR, LAI
  - Local, restrictive and expansive albedo
  - Cloud heights and winds

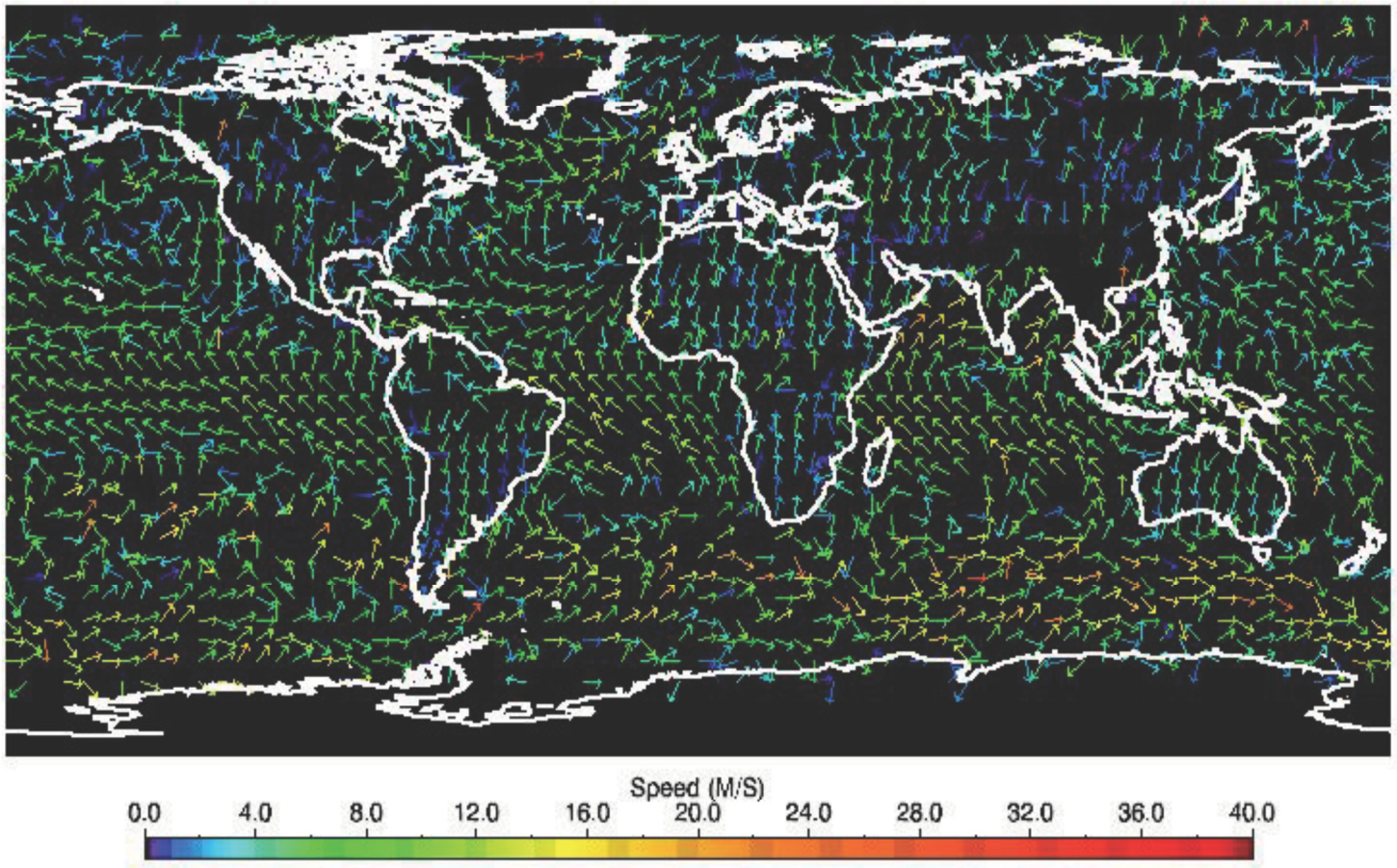




- Reported on 0.5 degree rectangular grid
- Stored in standard HDF-EOS format
- View JPEG images online at: http://eosweb.larc.nasa.gov/PRODOCS/misr/level3/overview.html
  - Animate through year's worth of data
  - View product by month or season
  - Download Level 3 HDF or NetCDF files

L3 Gridded Height-Resolved Winds

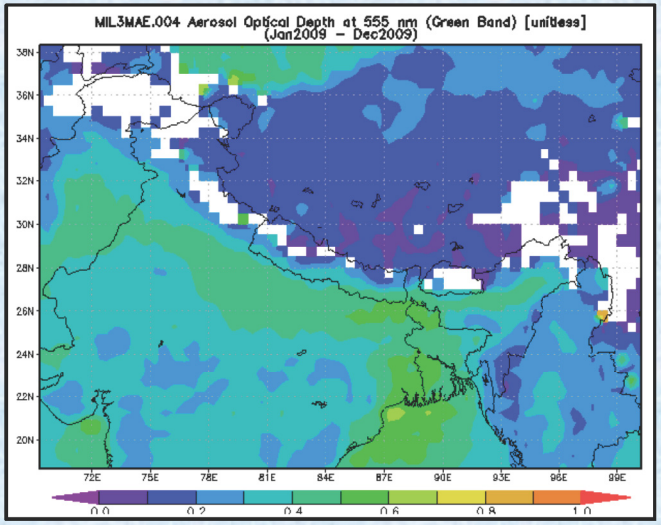
Monthly mean winds August 2005 (0.5-1 km altitude)

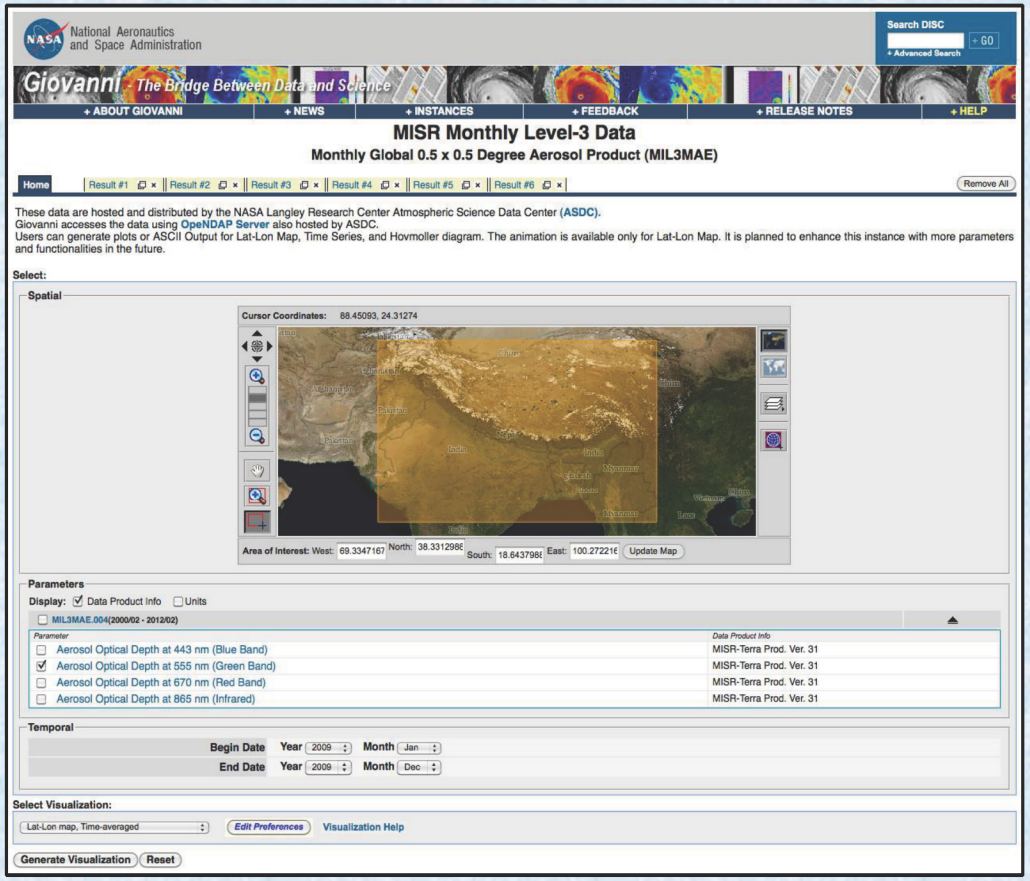


Level 3 Global Data Products - Giovanni

- **View images online at**
  http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=MISR_Monthly_L3

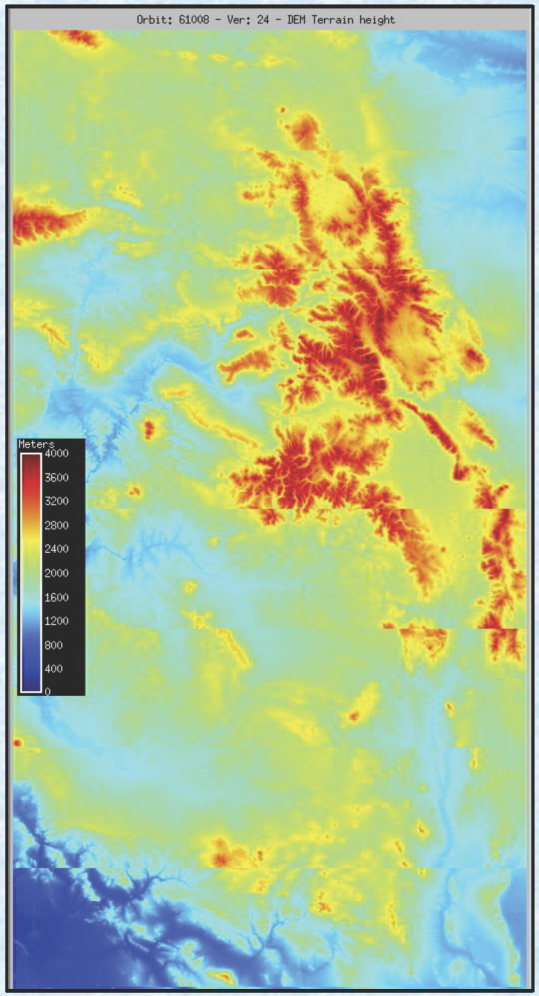
- **Similar to DAAC tool but:**
  - **Contains globally gridded images of Level 3 aerosol optical depth only**
  - **Allows geographic zoom**
  - **Allows download of ASCII data**





Ancillary Product Types

- AGP (Ancillary Geographic Product)
  - Latitude, longitude, terrain heights (digital elevation model), surface feature codes, at 1.1 km resolution
  - One file per MISR path
  - MISR_AM1_AGP_P028_F01_24.hdf
- ARP (Ancillary Radiometric Product)
  - Includes 4 separate files whose data are used to correct measured radiances during processing
  - One file is updated after each bi-monthly in-flight calibration to accommodate sensor degradation
- SMART (Simulated MISR Ancillary Radiative Transfer)
  - Includes 12 separate files totaling > 5 Gbytes; 6–dimensional
  - Model equivalent reflectances etc, corresponding to various aerosol mixtures, sun and view geometries, surface types and meteorological conditions
- TASC (Terrestrial Atmosphere and Surface Climatology)
  - One data file for each month gridded to 1 degree resolution
  - Zonal and meridional surface wind speeds, snow-ice mask, ozone abundance, atmospheric temperature, pressure, etc.



Terrain height from AGP

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- **Davies, R., Molloy, M., "Global cloud height fluctuations measured by MISR on Terra from 2000 to 2010", 2012. Geophys. Res. Lett. 39, doi:10.1029/2011GL050506.** http://www.outlookseries.com/A0993/Science/3974_Roger_Davies_University_Auckland_Cloud_height_changes_may_lower_global_temperature_Roger_Davies.htm
- **Diner, D.J., et.al., 1998. "Multi-angle Imaging SpectroRadiometer (MISR). Instrument Description and Experiment Overview", IEEE Trans. on Geosci. and Remt. Sens., 36, No. 4.** http://ieeexplore.ieee.org/iel4/36/15154/00700992.pdf
- **J-P. Muller, et.al., 2002, "MISR stereoscopic image matchers: Techniques and results", IEEE Trans. Geosci. Remt. Sens. 40, 1547-1559.** http://eprints.ucl.ac.uk/9853/1/9853.pdf
- **MISR ATBDs (Algorithm Theoretical Basis Documents)** http://eospso.gsfc.nasa.gov/eos_homepage/for_scientists/atbd/viewInstrument.php?instrument=19